Controlling Method of Indoor Environment in Sickroom with Ceiling Induction Diffusers
(Part 3) Indoor Environment under Cooling Condition in Sickroom with Four Beds

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As the demand of high quality of indoor environment and energy conservation gets higher, the radiant air-conditioning system has become the focus of attention. In this paper, the experiments were conducted by changing four parameters in full scaled room with Ceiling Induction Diffusers of Low Speed (CID). The influence of four relevant parameters on the distributions of indoor temperature and contaminant concentration was examined.

1. Introduction
In recent years, the comfort air conditioning system attracted more and more attention. Many scholars pay close attention to the radiant air-conditioning system, according to its high system efficiency and outstanding comfort1, 2). To solve the aforementioned issue, the induction radiant air-conditioning was proposed.

In induction radiant air-conditioning system, because of the effect of air pressure, the indoor air is induced and mixed with outdoor air. The mixed air is rectified and blown into the interior though radiant panels, the air supply rate is reduced, which can decrease the power of conveyance. In addition, it can be regarded as comfort air conditioning systems with low draft. To verify the characteristics of the air-conditioning method with Ceiling Induction Diffusers (short for CID), the experiments were carried out. In this paper, the results of experiments under cooling condition, assuming that there was only one patient in the ward was analysed. This paper was the integration of previous reports3, 4).

2. Experiment method
Experiments are conducted in a full scaled model room with four beds on November 2nd, 2015~November 20th, 2015, in the showroom of KIMURA KOHKI Corporation. The size of experimental room is 7.35m(d)×5.35m(w)×2.42m(h), as shown in Fig.1 and Fig.2. The north wall and east wall were insulated with polystyrene foam. Two square return louver (275mm×275mm) and four rectangular supply inlets (1200mm×500mm) with induction panel are located on ceiling above beds (one for each bed). Rigid diffusion fins are installed on each of aluminum inlet plates.

The outdoor air is heated by the heater in the experiment room, accordingly, the outdoor air temperature rises to 32°C. The mannequins with heating-cable is used as human simulators. Heat generation rate of each mannequin is 40W as sensible heat load of patient. Black lamp, which assumed equipment heat was set aside of each bed at the height of 1000mm from floor. The power of each lamp was 90W.

There were four pieces of heating carpets used as heat gain from windows, which were pasted on the both side of styrene foam, the thickness of the set was 15mm. The heat generation rate of each was 500W, that is to say heat flux was 2000W in total. In addition, the power of illumination in the labouratory is 182W, in total.
The tracer gas step-up method and decay method were applied. CO₂ as tracer gas was emitted from the chest of each heated person simulator. Flow rate of CO₂ is controlled at CO₂ as tracer gas was emitted from the chest of each heated person simulator. A person simulator is made of tin cylinder (φ150mm, H1500mm). Total Flow rate of CO₂ is controlled at 1.5L·min⁻¹ by mass flow meter. Wall surface temperature, indoor air temperature and CO₂ concentration were measured after the steady state confirmed.

The measurement points of temperature and CO₂ concentration are shown in Fig.3. CO₂ concentration (P1-P10) is measured at 4 points vertically (i.e. 40 points for all). The wall surface temperature is collected at 3 points vertically (W1-W9), 27 points in total, using T-thermocouple (Data logger Cadac 3, Etodenki Corporation). Twelve straight poles were set in the laboratory, and 8 measurement points were set on every pole. The air temperature is measured at 12 points (P1-P12) horizontally and 8 points vertically, i.e. 96 points in total. It is worth mentioning that, on each pole at four heights of 100mm, 600mm, 1100mm and 1700mm, both the temperatures and concentration were collected using CO₂ recorders (TR-576, TR-76Ui, T&D Corporation ), and the rest four points were measured by T-thermocouple. Namely, the temperatures of red circle points on poles were collected by T-thermocouple, and temperatures of green square points were measured by CO₂ recorders. Then every 30 seconds, the instantaneous value was recorded with the two kinds of measuring instruments.

As a result of Venturi effect, indoor air is induced and mixed with the primary air. The proportion of indoor air is 60%, by comparison, the primary air accounts for 40% in total mixed air. When outdoor air flow rate is two times per hour, in other words, the airflow rate from each air conditioner is 213m³·h⁻¹, in which the airflow rate of outdoor air and return air are 50m³·h⁻¹ and 163m³·h⁻¹, respectively (Fig. 4). Table 1. shows the experimental conditions of cases mentioned in this paper.

Table 1 Experimental conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>Condition</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Case 1</td>
<td>2-PR-C</td>
<td>2: air change rate of outdoor air is 2 times·h⁻¹</td>
</tr>
<tr>
<td>Case 2</td>
<td>2-PR-NC</td>
<td>PR: CO₂ is emitted from right of perimeter</td>
</tr>
<tr>
<td>Case 3</td>
<td>2-IR-NC</td>
<td>IR: CO₂ is emitted from right of interior</td>
</tr>
<tr>
<td>Case 4</td>
<td>4-PR-NC</td>
<td>C: with curtain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC: without curtain</td>
</tr>
</tbody>
</table>

3. Influence of parameters on vertical temperature and contaminant concentration distribution

The diagrams (Fig.5-Fig.12) show the relationship between the vertical profile of temperature and the height. In Fig.5-Fig.12, the temperatures at measurement points were collected by T-thermocouple, while, hollow circle and square indicates the temperatures at points measured by CO₂ recorders.

3.1 Influence of tracer gas positions

The cases, in which CO₂ was emitted at the location of PR (we assumed the perimeter side) and IR (interior side) were conducted, under the condition of air change rate of 2 times·h⁻¹, without curtain around bed and no standing persons (case 2 and case 3). Fig.5 shows the measured results of vertical profile of temperature. Theoretically, there should be no difference of temperature by changing position of tracer gas, as the position of CO₂ generation seems not to have some effect on temperature distribution. Actually, according the experiment result, the values of each relevant position are absolutely same, that is to say, the two curves coincide. This coincidence of temperature shows the accuracy and steady condition of experiments.
concentration distribution. As outdoor air concentration is defined as 0, while, the concentration of exhaust as 1, it is clear from the figures, CO₂ spread to the entire room well, when emitted at IR. We can see the uniform contaminant distribution when CO₂ was emitted at PR, except for the higher concentration at the points of P8. It is clear from the figure, tracer gas positions have less effect on the concentration distribution.

### 3.2 Influence of airflow rate of outdoor air

On the premise of the other three conditions fixed, the experiment was carried out by changing the air change rate of outdoor air from 2 times•h⁻¹ to 4 times•h⁻¹. When the airflow rate of outdoor air is 2 times•h⁻¹ and 4 times•h⁻¹, Vertical profile of temperature is shown in Fig.7. The range of variation is from 22 °C at the floor to 20 °C at the height of 2110mm. Except for P12, the temperature profile is slightly high at the height of 1700mm. It may be caused by apparatus error of measurement instruments. At the height of 2320mm and 2420mm, the temperatures rise to the level which approximates the temperature of the floor. It is also seen that the temperatures of P4 and P8 are slightly higher than others, which are affected by the influence of heat air flow from windows. There are similar vertical temperature distributions in both cases (case 2 and case 5). However, it can be found that temperature under the condition of airflow rate of 4 times•h⁻¹ is lower than that of 2 times•h⁻¹. The temperature differential between the two cases is about 2 °C . According to the chart in Fig.8, there is no large difference of normalized concentration at each measurement point, except for P8 near the contaminant source. The normalized concentration of the points of P8 at the height of 100mm and 600mm are slightly higher, due to the increase in airflow rate. There is no appropriate explanation of the relationship between CO₂ concentration and airflow rate at P8 at this stage.

### 3.3 Influence of with or without curtain around beds

Fig.9 demonstrates temperature profile compared with the condition of hanging curtain (case 1) and without curtain (case 2). The diagram indicates that the similar vertical temperature distribution in both cases. It is apparent that in case 1 (with curtain) temperature is 1 °C higher than that in case 2 (without curtain). The result may be caused by the difference of outdoor air temperature, according to the temperature differential between the ceiling surface temperature and the floor temperature. Fig.10 is a graph which illustrates the normalized concentration distribution.
In this paper, the influence of four relevant parameters on the distributions of indoor temperature and contaminant concentration was examined. The detailed analysis will be conducted by CFD in the future.

3.4 Influence of two standing person simulators

In case 4, the mannequins with 60W-heat generation rate of each mannequin as sensible heat load are placed on each side of bed, which is near to the window and on the right side. Keeping other conditions constant, case 2 and case 4 times temperature is arranged in Fig.11. There is no large difference between case 4 and case 2. The trend of temperature distribution is consistent, except for the slight temperature difference at P8 (near the two standing persons). It is caused by the sensible heat load of the two standing person simulators. Furthermore, from Fig.12, there are a lot of similarities of vertical normalized concentration distribution between the two cases.

4. Conclusion

In this paper, the influence of four relevant parameters on the distributions of indoor temperature and contaminant concentration was examined. The detailed analysis will be conducted by CFD in the future.

References

3) Ying Li, Yamanaka Toshio, Kotani Hisashi, Momoi Yoshihisa, Sagara Kazunobu, Yun Chen. Method of Indoor Environment in Sickroom with Ceiling Induction Diffusers. (Part 2) Indoor Thermal Environment under Cooling Condition in Sickroom with Four Beds Analysis. Architectural Institute of Japan (For publication)
4) Yun Chen, Yamanaka Toshio, Kotani Hisashi, Momoi Yoshihisa, Sagara Kazunobu, Ying Li. Controlling Method of Indoor Environment in Sickroom with Ceiling Induction Diffusers. (Part 3) Ventilation Performance under Cooling Condition in Sickroom with Four Beds (in Japanese, for publication)